

# Effects of temperature and salinity on the oxygen consumption in clams

BY

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(With eight text-figures)

The importance of oxygen as an oxidizing agent in energy releasing mechanism is well known. Utilization of oxygen is, therefore, a direct measure of degree of activity, food conversion and heat production (Bishop 1950). In lamellibranchs, which are filter-feeders, the current of water drawn through the inhalent siphon is used for feeding and respiration. The fluctuations in the estuarine environment where clams are found, are, therefore, bound to influence the oxygen-consumption in clams. Dam (1935, 1954) has studied oxygen utilization in *Mya arenaria* and scallops. Berkeley (1921, 1923) has studied anaerobic respiration in pelycypod mollusks. Mitchell (1912) and Hazelhoff (1938) have given oxygen requirements of shellfish and other invertebrates. Galtsoff & Whipple (1930) have investigated the oxygen-consumption in normal and green oysters under different conditions. The oxygen-consumption of tissues in *Venus merceraria* has been studied by Hopkins (1948).

Amongst various other factors that affect oxygen-consumption, the influence of body size and temperature on respiration of some animals has been studied by Kleiber (1947), Zeuthen (1947, 1953), Scholander *et al.* (1953), Rao & Bullock (1954) and Dawson *et al.* (1956). But most of these studies are made on the arctic and temperate forms. Wolvekamp & Waterman (1960) have reviewed respiration in crustacea. Studies on oxygen-consumption in tropical poikilotherms have recently attracted attention (Job 1955, Saroja 1959, and Parvatheswararao 1959, 1960).

The influence of salinity on oxygen-consumption has been studied by Bloch and Schlieper (1953) in *Asterias rubens*, Eliassen (1952) in *Artemia salina*, Potts (1954) in brackish and fresh water animals, Schlieper (1955) in *Mytilus edulis*, Lofts (1956) in *Palaemonetes varians* and Gross (1957) in some decapod crustacea. The only work of this type in tropical species is that of Gopalkrishna (1953) on penaeid prawns and Rao

(1958) on *Metapenaeus monoceros*. No work has been done on the oxygen-consumption in clams from tropical waters. The present investigation was, therefore, undertaken with a view to studying the effects of temperature and salinity on the oxygen-consumption in the common clams *Meretrix meretrix* and *Katelysia opima*.

### MATERIALS AND METHODS

Clams collected from Kalbadevi estuary were stored in the same manner as described in the earlier paper (Ranade & Kulkarni 1972). For determining oxygen-consumption in clams, the method adopted by Saroja (1959) was followed, except that instead of a cork to close the respiratory chamber, a three centimetre layer of liquid paraffin was put on the surface of the water to stop gaseous exchange between the sea water in the respiratory chamber and the atmosphere as suggested by Galtsoff & Whipple (1930).

Temperature being an important factor in controlling the rate of oxygen-consumption, care was taken to keep the required temperature constant, with a variation of only  $\pm 1^{\circ}\text{C}$ , by providing a thermostat. Observations on the rate of oxygen-consumption were made at three different temperatures namely 20, 30 and  $40^{\circ}\text{C}$  at a constant salinity (34‰). The temperature of the water available in the laboratory varied between  $28^{\circ}$  and  $30^{\circ}\text{C}$ . For measuring oxygen-consumption at  $40^{\circ}\text{C}$ , the respiratory-chamber was kept in an aquarium tank filled with water, heated to  $40^{\circ}\text{C}$  by means of a heater and maintained at this level by a 'Sunvic' thermostat. For obtaining a temperature of  $20^{\circ}\text{C}$ , ice was used in the aquarium tank in which the respiratory-chamber was kept and the tank in turn was kept in a thermocole insulated box.

The differential values of oxygen in the samples of water from the respiratory-chamber before and after the experimental period i.e. one hour, gave the amount of oxygen consumed. The clams were taken out immediately after the experiment and shelled. The wet weight of the flesh was taken after removing the extra water by using a blotting paper.

In order to study the effect of salinity on the oxygen-consumption, observations were made at three different salinities namely 34 ‰, 25.5 ‰ and 17 ‰, which was equal to 100 ‰, 75 ‰ and 50 ‰ sea water respectively. In these experiments the temperature was kept constant at  $30^{\circ}\text{C}$ . The lower grades of salinities were prepared as usual, by diluting sea water with distilled water.

As the clams remain buried in the sand in the natural habitat, the respiratory-chamber was painted black, to avoid activity of clams on account of light. The oxygen contents of water were determined by Winkler's method as described by Barnes (1959).

## ANALYSIS OF DATA

The rate of oxygen-consumption was plotted as a function of body weight (weight-specific) on a double logarithmic grid. Such a plot over an adequate weight range gives a straight line with a negative slope (Dehnel 1960).

The regression of oxygen-consumption on body weight assumes a form :

$$O_2 = aW^b \dots\dots$$

$$\text{or } \text{Log } O_2 = \text{Log } a + b \text{ Log } W.$$

where  $O_2$  is the volume of oxygen consumed in ml,  $W$  is the weight of the body in grams and  $a$  and  $b$  are constants being respectively the intercept and the slope of the line or the exponent. The regression of oxygen-consumption on body weight at three different temperatures and salinities were calculated separately.

## RESULTS

Results of the oxygen-consumption at various temperatures in both the species are summarised in Tables I and II and are plotted as size metabolism curves in Figs. 1 and 2.

TABLE I

TOTAL OXYGEN CONSUMPTION IN *M. meretrix* AT DIFFERENT BODY WEIGHTS AND AT DIFFERENT TEMPERATURES

S. No.	Weight in gm	Oxygen consumed ml/hr		
		20°C	30°C	40°C
1	0.40	0.16	0.30	0.42
2	0.60	0.17	0.28	0.43
3	1.00	0.30	0.42	0.54
4	1.25	0.36	0.51	0.60
5	1.58	0.45	0.60	0.68
6	1.99	0.57	0.66	0.80
7	2.51	0.75	0.78	0.83
8	3.16	0.93	0.96	0.95
9	4.00	1.14	1.17	1.15

TABLE II

TOTAL OXYGEN CONSUMPTION IN *K. opima* AT DIFFERENT BODY WEIGHTS AND AT DIFFERENT TEMPERATURES

S. No.	Weight in gm	Oxygen consumed ml/hr		
		20°C	30°C	40°C
10	0.54	0.35	0.40	0.55
11	0.85	0.38	0.46	0.58
12	1.03	0.49	0.65	0.69
13	1.52	0.65	0.80	0.85
14	2.00	0.80	1.05	1.15
15	2.25	0.95	1.08	1.19
16	3.02	1.05	1.38	1.24

*Oxygen-consumption as a function of body size in relation to temperature :*

From the study of the data given in Tables I and II it could be seen that the oxygen-consumption in clams increases with increase in body weight at all the temperatures studied. However, this increase in oxygen-consumption with increase in body weight is not the same at the three temperatures, which is apparent from the regression coefficients of the size metabolism curves. The regression coefficient of oxygen-consumption in relation to body size is maximal in both the species at 20°C and decreases as the temperature increases. The straight lines of the size metabolism curves also suggest that throughout the weight range studied the oxygen-consumption increases with the same power of body weight. From Tables I and II, it could be also seen that at any given temperature, the oxygen-consumption per unit of time is lesser in smaller clams than in larger ones.

From the curves given in Figs. 1 and 2 the values of weight specific  $QO_2$  or the unit oxygen-consumption, ( $O_2$  ml/gm/hr), were calculated for the representative weight of clams. These are given in Tables III and IV.

TABLE III

OXYGEN-CONSUMPTION PER GRAM OF BODY WEIGHT PER HOUR IN *M. meretrix* OF DIFFERENT WEIGHTS AND AT DIFFERENT TEMPERATURES

S. No.	Weight in gm	Oxygen ml/gm/hr		
		20°C	30°C	40°C
1	0.50	0.32	0.54	0.76
2	0.75	0.30	0.48	0.62
3	1.00	0.29	0.42	0.53
4	2.00	0.29	0.35	0.39
5	3.00	0.28	0.30	0.31
6	4.00	0.28	0.29	0.29

The values are calculated from the size metabolism curves presented in Fig. 1.

TABLE IV

OXYGEN-CONSUMPTION PER GRAM OF BODY WEIGHT PER HOUR IN *K. opima* OF DIFFERENT WEIGHTS AND AT DIFFERENT TEMPERATURES

S. No.	Weight in gm	Oxygen ml/gm/hr		
		20°C	30°C	40°C
7	0.50	0.54	0.72	0.94
8	0.75	0.48	0.60	0.74
9	1.00	0.45	0.55	0.66
10	2.00	0.39	0.43	0.45
11	3.00	0.38	0.42	0.42
12	4.00	0.32	0.32	0.32

The values are calculated from the size metabolism curves presented in Fig. 2.



From Tables III and IV, it would be seen that the unit oxygen-consumption ( $O_2$  ml/gm/hr) decreases with increasing body weights of clams at all temperatures studied. However, this decrease in unit oxygen-consumption is more conspicuous at  $40^\circ\text{C}$  and  $30^\circ\text{C}$  than at  $20^\circ\text{C}$ .

*Oxygen-consumption as a function of temperature :*

The values of regression coefficient 'b' are given in Table V.

TABLE V

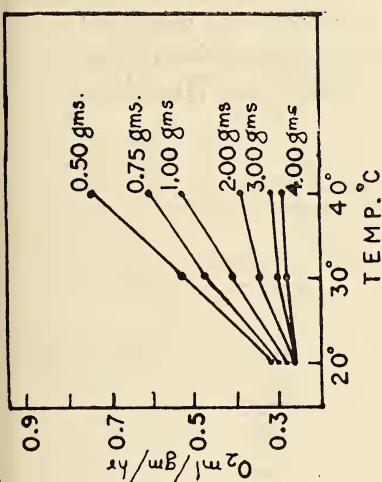
Species	Temperature		
	$20^\circ\text{C}$	$30^\circ\text{C}$	$40^\circ\text{C}$
<i>M. meretrix</i>	0.94	0.66	0.57
<i>K. opima</i>	0.75	0.66	0.50

The size metabolism curves given in Figs. 1 and 2 show that the 'b' (Table V) value decreases with increase in temperature and in *M. meretrix* is 0.94 at  $20^\circ\text{C}$ , 0.66 at  $30^\circ\text{C}$  and 0.57 at  $40^\circ\text{C}$ ; whereas in *K. opima* it is 0.75 at  $20^\circ\text{C}$ , 0.66 at  $30^\circ\text{C}$  and 0.50 at  $40^\circ\text{C}$ . This decrease in 'b' value with increase in temperature indicates that the increase in oxygen-consumption in larger clams with increase in temperature is lesser than in smaller clams, and therefore, smaller clams can be regarded as more sensitive to temperature changes than the larger ones.

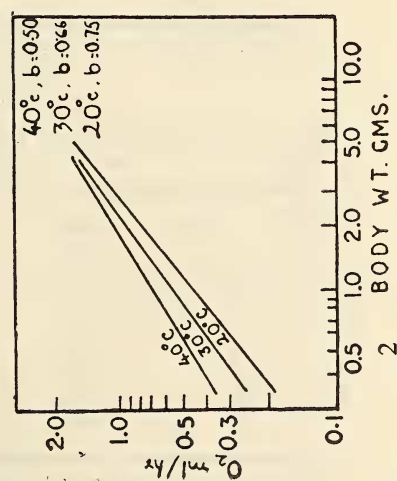
The unit oxygen-consumption values of clams of different weights are given in Tables III and IV and are plotted as rate-temperature curves in Figs. 3 and 4. The examination of these curves also indicates that the weight or body size of the clam is an important parameter in influencing the pattern of metabolic response at various temperatures. It will also be seen from these curves that the smaller clams are more sensitive to temperature changes than the larger ones in both the species studied. Thus in 1.00 gm clam of *Meretrix meretrix* the weight specific  $QO_2$  rises from 0.42 to 0.53 when the temperature rises from  $30^\circ\text{C}$  to  $40^\circ\text{C}$  and drops from 0.42 to 0.29 when the temperature drops from  $30^\circ\text{C}$  to  $20^\circ\text{C}$ . The corresponding rise and fall in 3.00 gm clam is very much less. In case of *K. opima* also a similar trend is seen, the weight specific  $QO_2$  rises from 0.55 to 0.66 with the rise in temperature from  $30^\circ\text{C}$  to  $40^\circ\text{C}$  and falls from 0.55 to 0.45 with the fall in temperature from  $30^\circ\text{C}$  to  $20^\circ\text{C}$ . The corresponding increase or decrease in case of 3.00 gm clam is much smaller.

*$Q_{10}$  as a function of temperature :*

To describe the magnitude of temperature effect on respiratory processes, the frequently used expression  $Q_{10}$  is a convenient

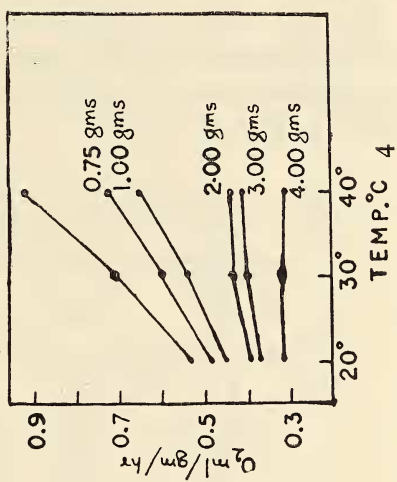


1



2

3



TEMP. °C 4

FIG. 1. Total oxygen-consumption in *M. meretrix* as a function of body size at different temperatures. (20°C, 30°C and 40°C).  
 FIG. 2. Total oxygen-consumption in *K. opima* as a function of body size at different temperatures. (20°C, 30°C and 40°C).  
 FIG. 3. Rate of oxygen-consumption ( $O_2$  ml/gm/hr) as a function of temperature in *M. meretrix*.  
 FIG. 4. Rate of oxygen-consumption ( $O_2$  ml/gm/hr) as a function of temperature in *K. opima*.

measure over the biological temperature range. It is a factor by which a reaction velocity is increased for a rise of temperature of 10 degrees.

$$Q_{10} = (K_2/K_1)^{\frac{10}{t_1 - t_2}}$$

where  $K_1$  and  $K_2$  are velocity constants corresponding to temperatures  $t_1$  and  $t_2$ .

The  $Q_{10}$  values of oxygen-consumption in clams were calculated from the data given in Tables III and IV for various weights and at various temperatures studied. The same are given in Tables VI and VII and are plotted in Figs. 5 and 6.

TABLE VI

$Q_{10}$  OF OXYGEN-CONSUMPTION IN *M. meretrix* IN RELATION TO BODY SIZE AND TEMPERATURE

S. No.	Weight in gm	20-30°C	30-40°C
1	0.50	1.70	1.40
2	0.75	1.60	1.29
3	1.00	1.40	1.26
4	2.00	1.26	1.15
5	3.00	1.07	1.03
6	4.00	1.03	1.00

The  $Q_{10}$  values are calculated from the data given in Table III.

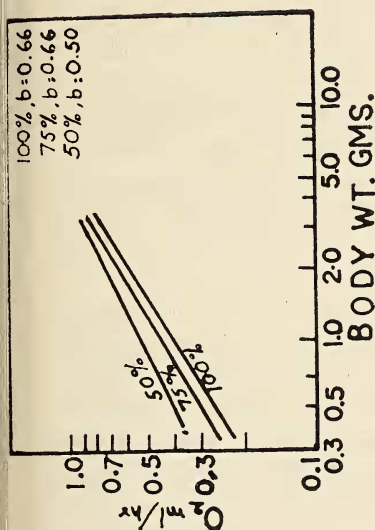
TABLE VII

$Q_{10}$  OF OXYGEN-CONSUMPTION IN *K. opima* IN RELATION TO BODY SIZE AND TEMPERATURE

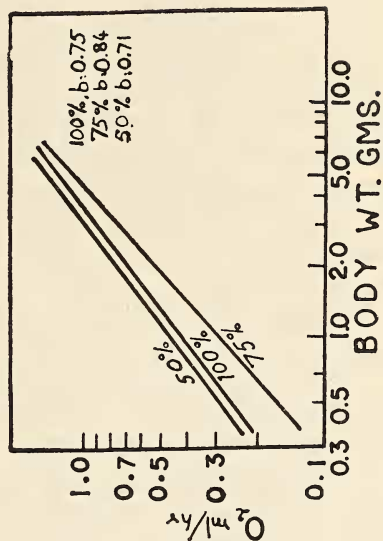
S. No.	Weight in gm	20-30°C.	30-40°C.
7	0.50	1.33	1.30
8	0.75	1.25	1.23
9	1.00	1.22	1.20
10	2.00	1.10	1.05
11	3.00	1.10	1.00
12	4.00	1.00	1.00

The  $Q_{10}$  values are calculated from the data given in Table IV.

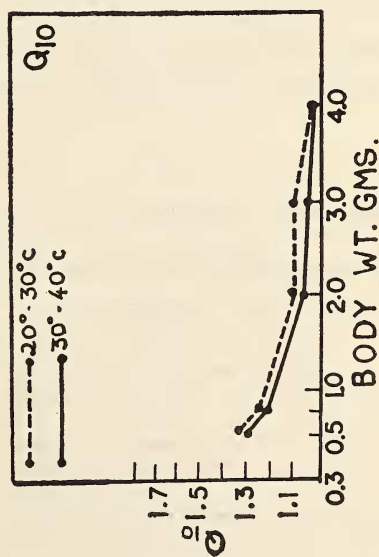
In case of *M. meretrix*  $Q_{10}$  values are size dependent at all temperatures studied. It systematically decreases with increase in body weight at all the temperatures studied. However, this trend is more conspicuous at temperature range of 20-30°C than at 30-40°C. It will also be seen that the decrease in  $Q_{10}$  at both the temperature ranges is more marked



5



7



8

FIG. 5.  $Q_{10}$  of oxygen-consumption in *M. meretrix* as a function of body size at different temperature ranges.

FIG. 6.  $Q_{10}$  of oxygen-consumption in *K. opima* as a function of body size at different temperature ranges.

FIG. 7. Total oxygen-consumption in *K. opima* as a function of body size at different salinities (100%, 75% and 50% sea water).

FIG. 8. Total oxygen-consumption in *M. meretrix* as a function of body size at different salinities (100%, 75% and 50% sea water).



in smaller clams than in the larger ones. Thus the  $Q_{10}$  between 0.50 gm and 2.00 gm clams, drops from 1.70 to 1.26 between 20-30°C and from 1.40 to 1.15 between 30-40°C whereas the corresponding drop between 2.00 and 4.00 gm clams is from 1.26 to 1.03 and 1.15 to 1.00 between temperatures 20-30°C and 30-40°C respectively. Similarly between 20-30°C and 30-40°C there is a decrease in  $Q_{10}$  from 1.70 to 1.40 in 0.50 gm clam whereas the corresponding decrease in 4.00 gm clam is from 1.03 to 1.00. This indicates that the  $Q_{10}$  of oxygen-consumption decreases with increasing temperature at all weights, such a decrease being once again more conspicuous in smaller clams than in larger ones. The higher values of  $Q_{10}$  in smaller clams at all the temperature ranges studied suggests that they are more sensitive to temperature changes than the larger ones.

In case of *K. opima* also, a similar trend is seen. The  $Q_{10}$  decreases with increasing body weights at all temperatures studied. This decrease is more conspicuous at lower temperatures (20-30°C) than at higher temperatures (30-40°C). The decrease is also more marked in smaller clams than in larger ones. There is also a decrease in  $Q_{10}$  with increasing temperature, the decrease being more conspicuous in smaller clams than in larger ones. The higher values of  $Q_{10}$  in smaller clams suggests that they are more sensitive to temperature changes than the larger ones.

*Oxygen-consumption as a function of body size in relation to salinity :*

The results of oxygen-consumption at various salinities in both the species are summarised in Tables VIII and IX and are plotted as size metabolism curves in Figs. 7 and 8.

TABLE VIII

TOTAL OXYGEN-CONSUMPTION IN *K. opima* AT DIFFERENT BODY WEIGHTS AND AT DIFFERENT SALINITIES

S. No.	Weight in gm	Oxygen consumed ml/hr			
		100%	75%	50%	sea water
1	0.60	0.29	0.36	0.45	
2	1.03	0.45	0.51	0.58	
3	1.52	0.52	0.59	0.66	
4	1.98	0.63	0.70	0.79	
5	2.20	0.70	0.81	0.87	
6	3.02	0.85	0.95	1.26	

TABLE IX

TOTAL OXYGEN-CONSUMPTION IN *M. meretrix* AT DIFFERENT BODY WEIGHTS AND AT DIFFERENT SALINITIES

S. No.	Weight in gm	Oxygen consumed ml/hr			
		100%	75%	50%	sea water
7	1.00	0.40	0.32	0.52	
8	1.25	0.50	0.38	0.58	
9	1.58	0.62	0.46	0.70	
10	2.00	0.73	0.58	0.80	
11	2.51	0.86	0.75	0.96	
12	3.16	0.95	0.96	1.10	

From the data given in Table VIII it could be seen that the oxygen-consumption in *K. opima* increases with increasing body weight at all the salinities studied. However, the regression coefficients of the size metabolism curves presented in Fig. 7 show that the increase in oxygen-consumption with increase in body weight is not the same at all salinities studied. The regression coefficient of oxygen-consumption in relation to body size is maximal in 100 % sea water ( $b=0.66$ ) and decreases as the salinity decreases. The straight lines of the size metabolism curves also suggest that throughout the weight range studied, the oxygen-consumption increases with the same power of body weight. It is also evident from Table VIII that at any given salinity the oxygen-consumption per unit time is less in smaller clams than in larger ones.

In case of *M. meretrix* (Table IX), however, the trend is slightly different. The oxygen-consumption increases with increase in body weight at all the salinities studied. However, this increase in oxygen-consumption with increase in body weight is not the same at all the salinities studied. The regression coefficient of oxygen-consumption on body weight is maximal in 75 % sea water ( $b=0.84$ ) instead of in 100 % sea water as in case of *K. opima*. The regression coefficient decreases as the salinity either increases above or decreases below 75 % sea water. This is rather an interesting behaviour and will be discussed later. The straight lines of the size metabolism curves suggest that throughout the weight range studied, the oxygen-consumption increases with the same power of body weight. From Table IX it is also evident that at any given salinity the oxygen-consumption per unit time is less in smaller clams than in larger ones.

From the curves given in Figs. 7 and 8 the values of weight specific  $QO_2$  or the unit oxygen-consumption ( $O_2$  ml/gm/hr) were calculated

for the representative weights of clams. These are given in Tables X and XI.

TABLE X

OXYGEN-CONSUMPTION PER GRAM BODY WEIGHT PER HOUR IN *K. opima* OF DIFFERENT WEIGHTS AND AT DIFFERENT SALINITIES

S. No.	Weight in gm	Oxygen ml/gm/hr		
		100%	75%	50% sea water
1	0.50	0.56	0.64	0.81
2	0.75	0.46	0.53	0.65
3	1.00	0.37	0.44	0.50
4	2.00	0.32	0.35	0.39
5	3.00	0.30	0.31	0.32
6	4.00	0.30	0.31	0.32

The values are calculated from the size metabolism curves presented in Fig. 7.

TABLE XI

OXYGEN-CONSUMPTION PER GRAM BODY WEIGHT PER HOUR IN *M. meretrix* OF DIFFERENT WEIGHTS AND AT DIFFERENT SALINITIES

S. No.	Weight in gm	Oxygen ml/gm/hr		
		100%	75%	50% sea water
7	0.50	0.52	0.36	0.62
8	0.75	0.48	0.34	0.56
9	1.00	0.40	0.32	0.50
10	2.00	0.34	0.27	0.40
11	3.00	0.33	0.25	0.37
12	4.00	0.31	0.25	0.33

The values are calculated from the size metabolism curves presented in Fig. 8.

From Table X it could be seen that in *K. opima* the unit oxygen-consumption decreases with increasing body weight at all the salinities studied, such a decrease being more conspicuous in 50% and 75% sea water than in 100% sea water. However, in *M. meretrix* (Table XI) though the unit oxygen-consumption decreases with increasing body weight at all salinities, the decrease is more conspicuous in 50% and 100% than in 75% sea water.

*Oxygen-consumption as a function of salinity :*

The values of regression coefficient 'b' are given in Table XII.

TABLE XII

Species	Percentage of sea water		
	100%	75%	50%
<i>K. opima</i>	0.66	0.60	0.50
<i>M. meretrix</i>	0.75	0.84	0.71

The size metabolism curves given in Figs. 7 and 8 show that the 'b' value of the curve varies with the salinity. In *K. opima* the 'b' value decreases with decrease in salinity which is 0.66 in 100%, 0.60 in 75% and 0.50 in 50% sea water. This decrease in 'b' value with decrease in salinity indicates that the increase in oxygen-consumption in larger clams with decrease in salinity is less than in smaller clams and can, therefore, be regarded as being more sensitive to salinity changes than the larger ones.

As stated above in case of *M. meretrix* the 'b' value is maximal in 75% sea water ( $b=0.84$ ) and decreases above ( $b=0.75$ ) and below ( $b=0.71$ ) this concentration. This decrease in 'b' value on either side of 75% sea water also appears to be on account of the less increase in oxygen-consumption in larger clams than in smaller ones with the change in the salinity. The smaller clams can, therefore, be regarded as more sensitive to changes in salinity either decrease below or increase above 75% sea water.

The unit oxygen-consumption values given in Table X for *K. opima* indicate that the weight or body size is an important parameter in influencing the pattern of metabolic response at various salinities. The smaller clams are more sensitive to salinity changes than the larger ones. Thus in case of 0.50 gm clam the weight specific  $QO_2$  rises from 0.56 to 0.64 and to 0.81 as the salinity decreases from 100% to 75% and to 50% sea water. However, the corresponding rise in 4.00 gm clam is very much less.

In case of *M. meretrix* (Table XI) the weight specific  $QO_2$  drops from 0.52 to 0.36 in a 0.50 gm clam as the salinity drops from 100% to 75% sea water and then rises from 0.36 to 0.62 as the salinity further drops to 50% sea water. But the corresponding drop and rise in a 4.00 gm clam is much less. This also indicates that the smaller clams are more sensitive to changes in the salinity than the larger ones.



## DISCUSSION

It has been well established that the metabolism of animals is considerably influenced by body size and temperature, of the environment. Similarly the tendency for the rate of metabolism in animals to vary with some power of body weight has been recognised and discussed by Zeuthen (1947, 1953). There is a general concept that the weight specific  $QO_2$  is higher for smaller animals than the larger ones when measured at a given temperature for a given species and, therefore, if the logarithm of rate of oxygen-consumption is plotted as a function of logarithm of weight a linear relationship is obtained.

On the basis of the magnitude of metabolic rate in relation to body size, Bertalanffy (1951) has classified animals into three major groups of metabolic types by using the slope of the regression line of the logarithm of metabolic rate against the logarithm of body weight. According to him the three types are :—

- (1) respiration surface-proportional, the allometric line showing a slope of  $2/3$  ( $b=0.67$ );
- (2) respiration weight proportional ( $b=1.00$ ) and
- (3) intermediate group which is neither surface nor weight proportional ( $b > 0.67$  and  $b < 1.00$ ).

However, the relationship of body size to metabolism has been a subject of controversy. In a majority of cases amongst fishes, Bishop (1950) and Fry (1957) have shown that the increase in oxygen-consumption with size is surface area dependent rather than weight dependent. On the other hand intermediate condition has been shown by Job (1955) in *Salvelinus fontinalis* ( $b=0.8$  to  $0.9$ ) and Parvatheswararao (1959) in *Eutophus maculatus* ( $b=0.77$ ). Job (1955) has discussed the metabolic response to body size in fishes and states, 'it seems rather likely that the Pisces fall into at least two of the Bertalanffy's metabolic types, some being of the first group i.e. surface proportional and others of an intermediate type neither surface nor weight proportional'. However, Parvatheswararao (1960) found that in *Puntius sophoro* the increase in oxygen-consumption is nearly weight dependent ( $b=0.96$  and  $0.91$ ) nearabout the habitat temperature ( $25^\circ\text{C}$  and  $30^\circ\text{C}$ ). He has further shown the influence of temperature on this relation, the increase in oxygen-consumption following surface area dependence at  $35^\circ\text{C}$  ( $b=0.59$ ) and intermediate condition at  $15^\circ\text{C}$  ( $b=0.86$ ).

Studies on the different invertebrate groups have also revealed that the value of 'b' changes within a group of animals and is not constant for the same species under different environmental conditions and at different developmental stages. This has been shown by Rao & Bullock (1954) and Zeuthen (1953). Thus for crustacea (Wolvekamp & Waterman

1960) the 'b' is generally between 0.67 and 1.00 i.e. between surface proportional to weight proportional. Kruger (1952) and Saroja (1959) have shown that the oxygen uptake is proportional to surface area in case of *Eisenia foetida* and *Megascolex mauritii* respectively. Recently Conover (1960) has shown that in case of *Artemia salina* the regression coefficient varies from 0.67 at 5°C to 0.93 at 13°C indicating two very different metabolic types. Zeuthen (1953, Fig. 4) has plotted metabolism and body size in different animals from eggs or larvae into mature stages. In the figure he has shown that in case of *Mytilus* sp. the 'b' value increases from 0.80 to 0.95 and then decreases to 0.65 as the animal grows.

In the present investigation it will be seen that in both the species studied the regression values ( $b=0.66$ ) nearabout the habitat temperature (30°C) indicate that the increase in oxygen-consumption is surface area dependent, however, an intermediate condition is seen in *K. opima* at 20 and 40°C. and in *M. meretrix* at 40°C., whereas the latter species shows that the oxygen-consumption may follow weight dependence at 20°C.

From the size metabolism curves presented in Figs. 1 and 2 it will be seen that the oxygen-consumption in clams increases with the same power of body weight at any given temperature throughout the weight range studied. Conversely, the unit oxygen-consumption decreases with increasing body weight this decrease being marked at 40°C. Thus the unit oxygen-consumption in *M. meretrix* decreases from 0.76 to 0.29 at 40°C, whereas the corresponding decrease at 30°C and 20°C is only from 0.54 to 0.29 and 0.32 to 0.28 respectively, between 0.5 and 4.0 gm clam. Similarly the decrease in *K. opima* is from 0.94 to 0.32 at 40°C the corresponding decrease at 30° and 20°C being from 0.72 to 0.32 and 0.54 to 0.32, respectively in 0.5 and 4.0 gm clam. If we consider 30°C as the habitat temperature then it will be seen that the size metabolism curves for 40°C and 20°C (Figs. 1 and 2) considerably deviate from the curve for 30°C. There is widest displacement of curves between 30°C and 20°C in *M. meretrix*, and less so in *K. opima* than between 30°C and 40°C. The curve for 20°C has the maximum slope. The displacement of curves is also more conspicuous in younger clams than in larger ones indicating that the former ones are more sensitive to changes in temperature than the latter.

In both the species of clams, the regression coefficients of size metabolism curves are shown to be temperature dependent. The 'b' values decrease with increasing temperature and appear to be correlated with the greater responsiveness of smaller clams than the larger ones. When the temperature is lowered (20°C) the curve towards lower weight ranges is pulled down, similarly when there is rise in temperature (40°C the curve rises mainly due to the more sensitive nature of smaller clams

than the larger ones to changes in temperature. Therefore, the smaller clams have higher  $Q_{10}$  values at these two temperature ranges.

In case of both the species studied, the  $Q_{10}$  of oxygen-consumption is size dependent at all the temperatures, decreasing with increasing body weight, the dependence being more marked in lower temperature ranges than the higher ones. The  $Q_{10}$  also decreases with increasing temperature, the decrease being more marked in smaller clams indicating that they are more sensitive to changes in temperature than the larger ones. Rao & Bullock (1954) have shown that in many poikilotherms the  $Q_{10}$  decreases with increasing body weight within the physiologically normal range of temperature. In the present case also the  $Q_{10}$  decreases with increasing body weight at all the temperature ranges studied and it also decreases with increasing temperature.

As in respect of metabolism in relation to temperature in clams, salinity also has considerable influence on their metabolic activity. In *K. opima* in 100% sea water, the increase in oxygen-consumption is surface area dependent ( $b=0.66$ ). The oxygen-consumption increases with decrease in salinity and in 75% sea water ( $b=0.60$ ) and in 50% sea water ( $b=0.50$ ) an intermediate condition is observed. In *M. meretrix* the oxygen-consumption shows an intermediate condition in all the salinities studied. However, in 100% and 50% sea water there is a slight tendency towards surface area dependence ( $b=0.72$  in 100% and  $b=0.71$  in 50% sea water). The slight high value of 'b' (0.72) in 100% sea water as compared with that at 30°C given earlier ( $b=0.66$ ) may perhaps be on account of the difference in the experimental temperature which in the present case was around 29°C.

From the size metabolism curves presented in Figs. 7 and 8 it will be seen that the oxygen-consumption in clams increases with the same power of body weight at any given salinity throughout the weight range studied. Conversely the unit oxygen-consumption decreases with increasing body weight, this decrease being more marked in 50% sea water. Thus the unit oxygen-consumption in *K. opima* decreases from 0.81 to 0.32 in 50% sea water whereas the corresponding decrease in 75% and 100% sea water is from 0.64 to 0.31 and from 0.56 to 0.30 respectively between 0.5 and 4.0 gm clam. Considering 100% sea water as the habitat salinity, in which the clams show minimum activity, it will be seen that the curve for 75% and 50% sea water considerably deviates from the curve for the 100% sea water, which has the maximum slope. It is also evident from the curves that the displacement is more conspicuous in smaller clams than in larger ones, indicating that the former are more sensitive to salinity changes.

In *M. meretrix* also the unit oxygen-consumption decreases from 0.63 to 0.33 in 50% sea water whereas the corresponding decrease in 75% and 100% sea water is from 0.36 to 0.25 and 0.52 to 0.31 respectively



between 0.5 and 4.0 gm clam. However, in this species the maximum slope ( $b=0.84$ ) is obtained in 75% sea water instead of 100% sea water ( $b=0.72$ ). This is rather a peculiar behaviour. Thus this species shows minimum activity in 75% sea water and not in 100% sea water as in *K. opima*. Therefore, unlike *K. opima* in which the oxygen-consumption increases with decrease in salinity in *M. meretrix* the oxygen-consumption decreases with decrease in the salinity from 100% to 75% sea water, in which the minimum activity is noticed. With further reduction in the salinity from 75% to 50% sea water, however, the oxygen-consumption increases. Considering the importance of 'b' value it is likely that *M. meretrix* is more at home in 75% sea water than in 100% sea water and, therefore, could be considered as more adapted to low salinity conditions than *K. opima*. From the experiments conducted on the salinity tolerance in the two species, it has been found that *M. meretrix* is more tolerant to low salinity conditions than *K. opima*, and has, therefore, succeeded better in invading estuaries and backwaters and is often found quite far up the river. The metabolic response in this species, in relation to salinity, showing minimum activity in 75% sea water (salinity=25.5‰), also lends support to this idea. Presuming that 75% sea water as the natural requirement for *M. meretrix* (ideal habitat salinity) it will be seen that the oxygen-consumption increases with either increase or decrease in this salinity, perhaps on account of the osmotic stress either ways, to be discussed later. Considering 75% sea water as ideal habitat salinity, it will be observed that the curves for other two salinities considerably deviate from the one for 75% sea water, the displacement being more conspicuous in smaller clams than the larger ones, indicating their more sensitive nature to changes in the salinity, either above or below the ideal salinity.

Considerable amount of work has been done on the effects of osmotic conditions of the metabolic activities. It is well-known that the animals show an increase in metabolism when placed in stress media. *Carcinus maenas* shows an increase in oxygen-consumption with decrease in salinity (Schlieper 1929). Flemister & Flemister (1951) found lowest oxygen-consumption in sea water (378 mM Cl/L) isotonic with the crab blood in case of *Ocypoda albicans*, but more hypotonic than the field conditions (480 mM Cl/L). They found that the oxygen-consumption increased as the sea water varied from isotonicity, highest being in hypotonic media. More or less similar results were obtained by Schwabe (1933) in case of cray fish *Potamobius fluviatilis*. The observations made by the abovementioned authors suggest that the increase in oxygen-consumption has resulted from increased osmotic work. But Gross (1957) has shown that in *Uca* oxygen-consumption did not always increase with osmotic stress. Marshall *et al.* (1935) also found that there was 30% reduction in oxygen-consumption when measured in 50% sea water



than in normal sea water (salinity=34‰). Potts (1954) also has shown that in *Eriocheir* only a very small fraction of increased oxygen-consumption represents osmotic work done. The results of Gross (1957), Marshall *et al.* (1935) and Potts (1954) are not in agreement with those of the earlier quoted authors.

The tendency for CO<sub>2</sub> to accumulate in lower salinities, resulting in increased respiratory rate has been suggested by Schlieper (1929). Another interpretation of increased oxygen-consumption with lowering of salinity was proposed by Schlieper (1935) on the idea that due to absorption of water in low salinity, the volume of tissue and surface is increased facilitating absorption and hence oxygen-consumption. Wikgren (1953) is of opinion that increase in oxygen-consumption is not due to osmotic regulation but either on account of swelling of tissues as suggested by Schlieper (1935) or by its influence on the endocrine balance. Violent attempts to escape from unfavourably low salinity, leading to extra muscular activity, resulting in increased oxygen-consumption has been suggested by Gross (1957) in the crab *Pachygrapsus*. Dehnel (1960) who studied metabolic response in *Hemigrapsus oregonensis* and *Hemigrapsus nudus* in relation to temperature and salinity, found results in the former species which could be considered as in accordance with Gross (1957) or Schlieper (1935); whereas in the other species the results were contradictory. Lofts (1956) compared respiratory rate of *Palaeomonetes varians* from two different populations, one from low saline environment (salinity=1.3‰) and the other from high saline environment (salinity=23.5‰), and found minimal respiratory rate in water of salinity 26.00‰ for high salinity population, a condition which was isotonic with the animal, whereas the minimal rate in low salinity population was found in salinity 6.00‰, a condition somewhat hypertonic to the environment in which these animals were found. Rao (1958) who compared oxygen-consumption in marine and brackish water populations of *Metapenaeus monoceros*, found that prawns from marine environment showed minimum activity in 100% sea water (salinity=35.5‰) whereas the minimum metabolic activity in prawns from brackish water environment was exhibited in 50% sea water (salinity=16.75‰), their oxygen-consumption increasing in 100% sea water. In both the groups of prawns the oxygen-consumption increased with decrease in salinity below the habitat salinity, and in the brackish water population the increase was also effected as the salinity increased to 100% sea water. He suggested that these differences may be due to osmotic adaptation and operation of a metabolic homoeostatic mechanism in relation to osmotic regulation.

The results obtained in the present investigation on the metabolic response in clams, though it involves two different species from the same environment, could be favourably compared on the strength of meta-

bolic response as those belonging to two groups of populations physiologically, one, *M. meretrix* as more adapted to low saline environment (25.5‰) and the other *K. opima* as adapted to marine environment (34.0‰). Therefore, the minimum activity in *M. meretrix* is found in salinity 25.5‰ and in *K. opima* in salinity 34.0‰. Hiscock (1953) states, 'In euryhaline marine species oxygen-consumption is at its lowest when the external medium is isotonic and rises as the later becomes hypo or hypertonic to the blood'. No data is available on the osmoregulation in these clams and, therefore, it is not possible to say whether isotonic condition is found in *M. meretrix* when exposed to 75% sea water and in *K. opima* in 100% sea water. It would be very interesting to study this aspect which might throw some light on the metabolic response in clams in relation to salinity. It is only suggested here that the differential metabolic response in clams to different saline media might be due to osmotic stress, though possibilities of increase in oxygen-consumption on account of absorption of water and subsequent swelling of the tissues, as suggested by Schlieper (1935) cannot be completely overruled in absence of any data on this aspect. In the experiments described earlier (Ranade & Kulkarni 1972) on the opening of the shell valves in relation to salinity, it has been shown that the opening of the valves in clams is progressively delayed as the salinity of the environment decreases. So in media hypotonic to blood, the closing of the shell valves relieves the animal from osmotic embarrassment. When the clams open after some time, depending on the strength of the solution, chloride ions are lost. These are perhaps replaced by active absorption from the environment as suggested by Krogh (1939). This process must require energy and hence the increase in the rate of oxygen-consumption with decrease in the salinity of the external medium.

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